MODIS

Moderate Resolution Imaging Spectroradiometer

NASA's Earth Observing System

National Aeronautics and Space Administration

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ith the inception of the U.S. Global Change Research Program, NASA, along with several other scientific institutions, has been charged with the task of developing a detailed understanding of the Earth and the dynamics of global climate change. Subsequently, work is underway to develop a Moderate Resolution Imaging Spectroradiometer (MODIS)—the flagship in a fleet of instruments that will monitor our planet from space.

MODIS

Cover: Highest ocean phytoplankton concentrations in shades of red, CZCS; land vegetation index in shades of green, AVHRR. Image provided by G.C. Feldman.

IS THE EARTH IN TROUBLE?

This is a widely asked question; unfortunately, too few data exist today to provide an adequate answer. Science reveals there have been many natural changes in the Earth's climate throughout history. Now there are strong indications that natural changes are being accelerated by human intervention, and that we are contributing to such hazards as global warming, rising sea level, deforestation, ozone depletion, acid rain, and reduction of biodiversity.

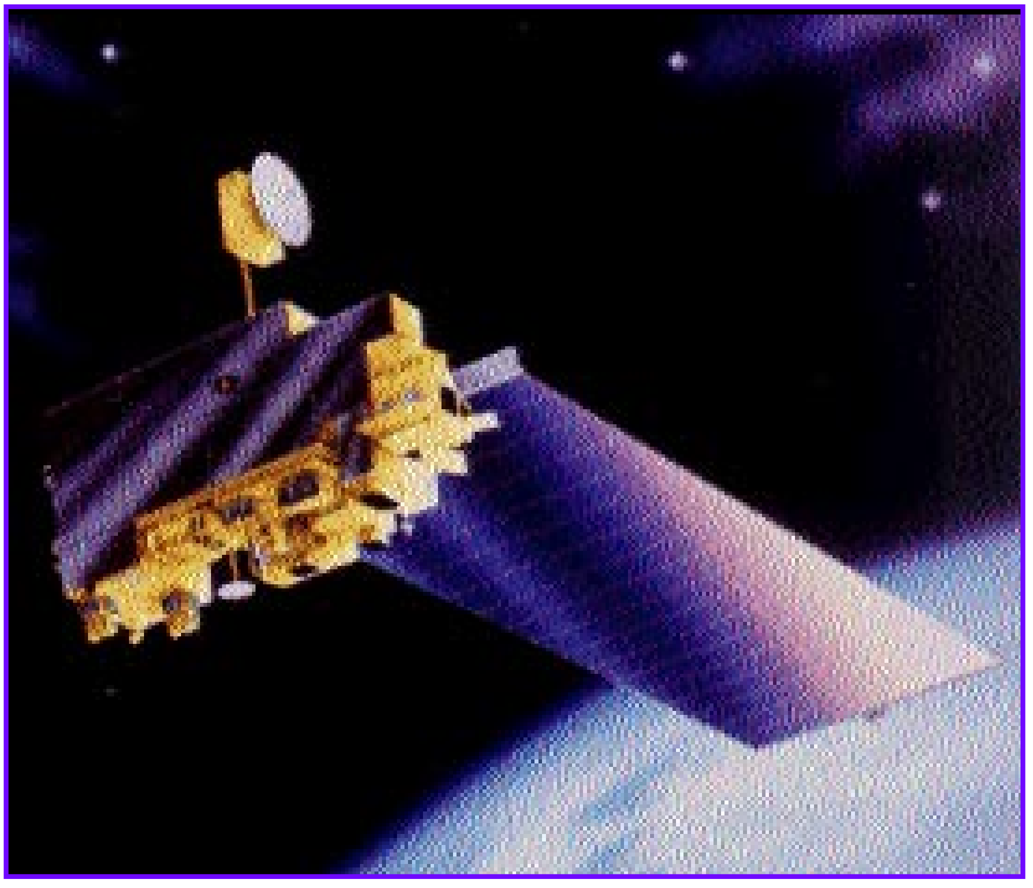
Through observations and measurements, scientists have learned that atmospheric constituents—such as clouds, gases, and aerosol particles—profoundly affect the Earth's land and oceans; and as changes occur on the land and in the oceans, they in turn profoundly affect the atmosphere. Scientists conclude that the relationship between land, oceans, and atmosphere is cyclical and tightly interwoven. So, in order to better understand natural global climate change, as well as mankind's role in accelerating these changes, scientists must study the Earth as a whole interacting ecosystem. The goal is to construct models of Earth's global dynamics—atmospheric, oceanic, and terrestrial—and predict changes before they occur.

Before scientists can begin to understand and accurately model global dynamics, they need information in the form of data. In order to differentiate short-term from long-term trends, as well as distinguish regional from global phenomena, these data must be collected every day for a long period of time (at least 15 years) and should represent every region of the Earth's lands, oceans, and atmosphere. Additionally, these data should be collected across a wide spectrum of energy, ranging from ultraviolet, through visible and infrared, to microwave radiation. Now NASA is developing new instruments—satellite sensors—to collect these data.

NASA's Earth Observing System

Satellite sensors serve as an effective means for collecting global data on a daily basis. NASA is working with the national and international scientific community to design, develop, and launch advanced satellite sensors with which scientists can observe and measure global dynamics. In the early 1980s, NASA began planning the Earth Observing System (EOS), the primary initiative in its Mission to Planet Earth. EOS consists of three components: a space-based observing system, a scientific research program, and a Data and Information System (EOSDIS). EOSDIS will process and store incoming data, as well as make them available to the research community.

The first EOS component, a space-based observing system, will consist of a series of polar-orbiting and mid-inclination satellites. Launches begin in 1998, with EOS AM-1, and extend over a period of at least 15 years. "AM" means the satellite will fly in a sun-synchronous polar orbit, descending southward across the equator in the morning; in the year 2000, EOS PM-1 will be launched into a sun-synchronous polar orbit ascending northward across the equator in the afternoon. Four years after that, EOS AM-2 will be launched, followed by EOS PM-2, and so on.



EOS AM spacecraft

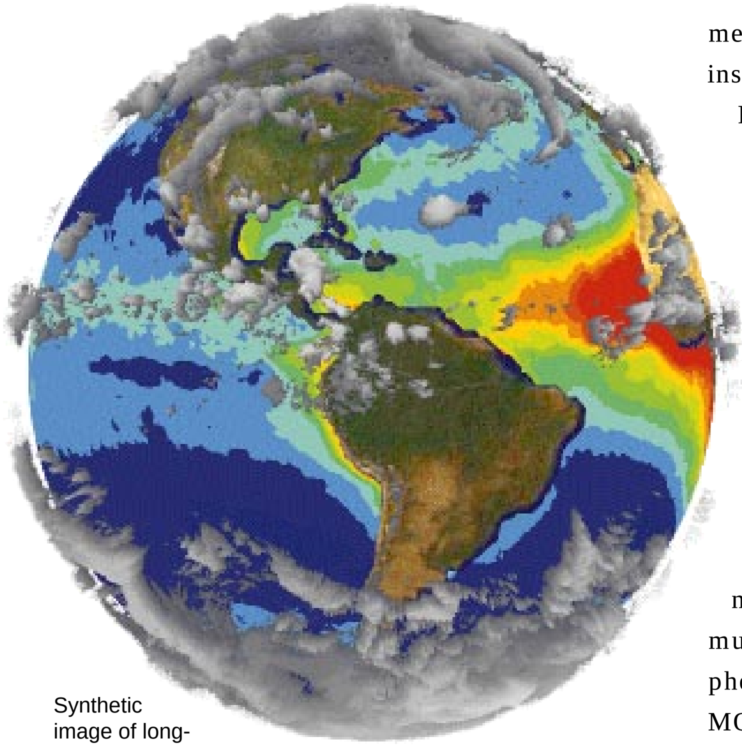


Image provided by R. B. Husar

Synthetic image of long-term oceanic aerosol pattern, continental vegetation index and daily cloud cover.

Moderate Resolution Imaging Spectroradiometer

The key instrument being developed to fly on each of the EOS AM and PM satellites is MODIS. MODIS' objective is to provide a comprehensive series of global observations of the Earth's land, oceans, and atmosphere in the visible and infrared regions of the spectrum in such a way as to view the entire surface of the Earth every two days. Here, the word "comprehensive" refers to the wide spectral range and spatial coverage, as well as the continuous coverage MODIS will provide over time.

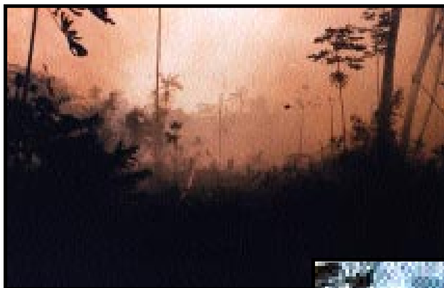
Additionally, MODIS is "comprehensive" in that it will continue to take measurements in spectral regions that have been and are currently being measured by other satellite sensors, or "heritage instruments." MODIS will extend data sets taken by such instruments as the Advanced Very High Resolution Radiometer (AVHRR), used for meteorology and monitoring sea surface temperature, sea ice, and vegetation; and the Coastal Zone Color Scanner (CZCS), used to monitor oceanic biomass and ocean circulation patterns. However, it should be noted that MODIS' development pushes state-of-the-art optical engineering—its performance will meet or exceed the capabilities of all of its heritage instruments.

"Comprehensive" also refers to the unified nature of MODIS' observations, necessary for multidisciplinary studies of land, ocean, and atmospheric processes and their interactions. In short, MODIS will be the primary tool on the EOS satellites for conducting global change research.

Our Changing Land

Currently, there are not adequate data to fully understand the effects of such critical issues as resource depletion and region-wide pollution. For example, we need more data to fully understand the effects of acid rain on the boreal forests of Europe and North America. In South America, the rain forest is rapidly being burned away to make croplands. Scientists will use MODIS to detect the rate of deforestation, which has become a major issue. Also of considerable interest are long-term data on the rate and extent of desertification at the margins of the world's deserts and arid regions. We need better global data on surface climate variables, such as temperature and humidity, as well as more accurate measurements of snow and ice cover. With the launch of MODIS, scientists will have better and more comprehensive data for improved monitoring of these often rapidly varying land surface features.

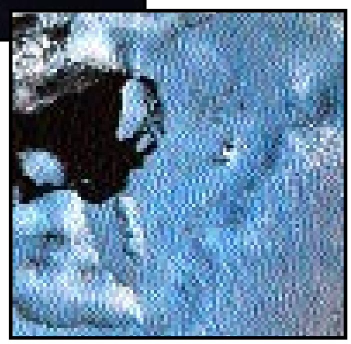
Using MODIS data, scientists will be able to construct improved global vegetation maps to provide up-to-date estimates of the distribution of the Earth's major vegetation formations. They will use MODIS to ascertain whether the vegetation is healthy or under stress. By globally monitoring subtle vegetation responses to stress in the biosphere—such as ozone—scientists can learn about both the nature and severity of the stress. They may, for example, derive information on the extent of freeze or drought damage to cropland. Timely global information on the overall status of agricultural crops throughout the growing season is vital for monitoring the world's food resources, yet this information is currently available for only a few areas.



(photo by Y.J. Kaufman)

BURNING OF TROPICAL RAIN FORESTS by humans contributes significantly to the release of CO_2, particulates, and trace gases into the atmosphere, affecting global climate.

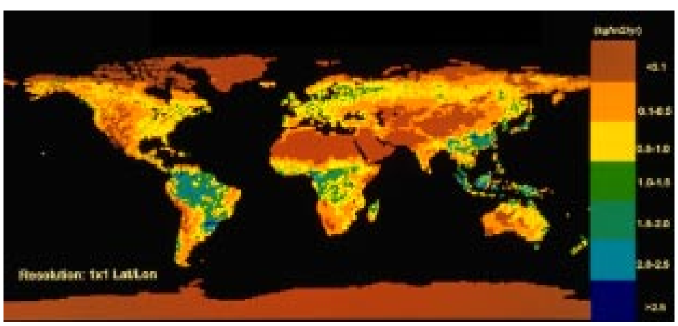
No one knows with certainty whether the amount of snow and sea ice in the world is growing or diminishing as a result of global warming. We do know that snow and sea ice have major impacts on the Earth's "hydrologic" (water) cycle and albedo, or reflected sunlight. MODIS will measure the snow and sea ice cover and help calculate its effect on global albedo. These measurements will help scientists better understand what happens to incoming solar radiation—how much is absorbed versus how much is reflected back into space. MODIS will also help scientists model increases in runoff and river discharge dynamics as a result of melting snow and ice, which will hopefully lead to better flood warning and irrigation management methods.



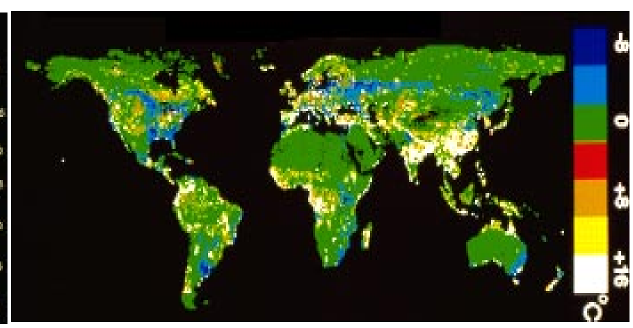
(Landsat, U.S. Geological Survey)

ICEBERGS breaking off from the West Antarctic ice sheet. Such iceberg "calving" serves as a major process by which land ice is discharged into the ocean, causing sea level to rise. The largest iceberg shown has a length of 32 kilometers.

MODIS will take daily measurements of surface climate and atmospheric conditions, such as temper-



GLOBAL TERRESTRIAL NET PRIMARY PRODUCTION (plant growth) was derived by translating AVHRR/NDVI satellite data into leaf area density for different biome types and, using an ecosystem model with climate data for 1987 to calculate daily photosynthesis, by summing the results to yield annual net primary production.



(Images provided by S. W. Running and R. Nemani)

CHANGES IN GLOBAL LAND SURFACE TEMPERATURES resulting from land cover changes due to human activities. These changes represent maximum deviations from ambient surface temperatures under natural vegetation during mid-summer, clear sky conditions. Increases in surface temperature are predominantly the result of deforestation, while decreases are due to irrigated agriculture.

ature and humidity. These data will be used for computer simulations of important biogeochemical processes in order to interpret changes in surface features. Additionally, surface climate data will be used to calculate the status and growth rates of crops, stress events, nitrogen and sulfur fluxes, and carbon dioxide exchange. Carbon dioxide is especially important in that scientists have identified it as a contributor to the recent global warming trend; however, our understanding of the global carbon cycle is limited.

The MODIS Team is working to develop a vegetation leaf area index (LAI) that will be used to calculate mass and energy exchange from vegetated surfaces. Today, global estimates of carbon storage in terrestrial plants vary by as much as an order of magnitude. Better estimates are needed for scientists to construct accurate models of the Earth's carbon cycle. Global estimates of LAI derived from MODIS data will allow scientists to much more accurately calculate the carbon stored on land, as well as the rate of exchange between plants and the atmosphere.

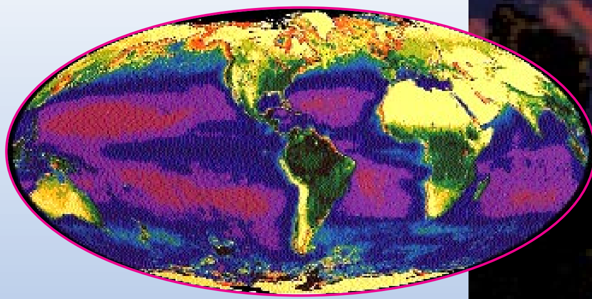
(Photos by D.W. Coats)

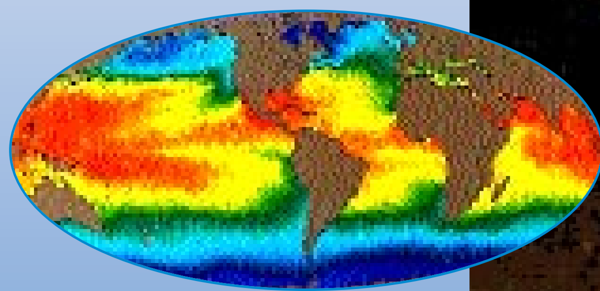
PHYTOPLANKTON IN THE OCEAN.

Our Changing Ocean

Scientists estimate that roughly the same amount of carbon dioxide (CO_2) is used by plants in the ocean for photosynthesis as is used by plants on the land. However, there are large differences in the turnover rates and reservoirs of carbon on land and in the ocean. Land ecosystems have large amounts of structural plant material with life cycles ranging from one year to centuries. The oceans, on the other hand, are dominated by unicellular plants—phytoplankton—that have life cycles of days. Land soil is a large reservoir of carbon and has a turnover time of many centuries; whereas dissolved organic material suspended in the ocean is similar in amount and turnover time to soil carbon, the carbon cycle of marine bottom sediments has a turnover time of millions of years.

Scientists have observed that over the last century, with the dramatic increase of biomass burning and fossil fuel burning, there has been a corresponding increase in CO_2 released into the atmosphere. Much of this CO_2 eventually enters the oceans and is used by phytoplankton for photosynthesis. The amount of CO_2 consumed by the phytoplankton depends heavily on ocean circulation which supplies nutrients to the upper layers where sunlight is abundant. Some fraction of particulate carbon produced by the phytoplankton sinks to the ocean floor—a long-term sink for atmospheric CO_2. The fraction is not well known, and is a source of a large uncertainty in the global carbon budget. Unravelling this complex system—called the "biological pump"—is difficult. Scientists wish to understand the coupling of physical and biological aspects of the carbon system in the ocean in order to estimate how changes in the oceans will affect the global CO_2 system as well as the population of phytoplankton, which is an essential link in the Earth's food chain. Hopefully, MODIS will help scientists answer important questions, such as: is productivity in the ocean changing, and how do the changes relate to increases in atmospheric CO_2? Would decreases in productivity accelerate CO_2





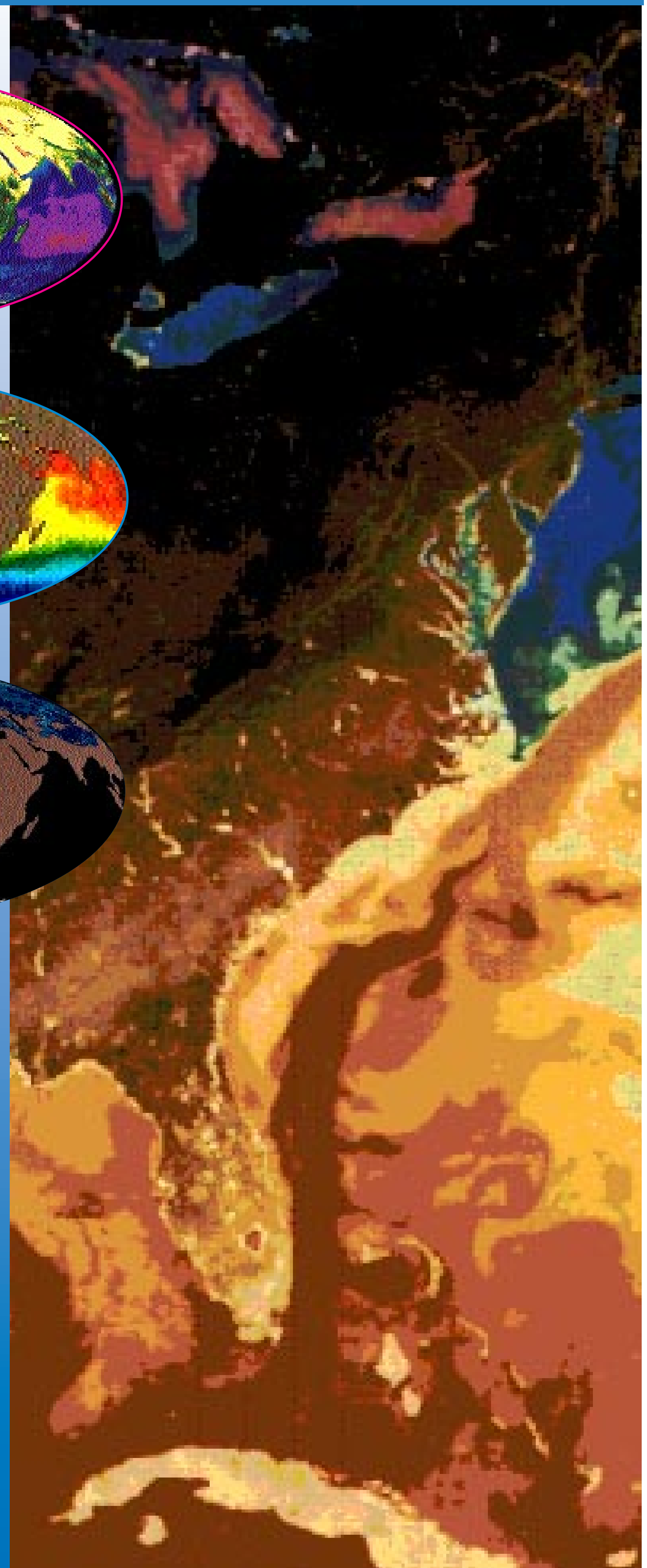
Images by G.C. Feldman

EARTH'S BIOSPHERE (top). Mean global distribution of phytoplankton concentrations as determined from measurements obtained by the Nimbus 7 Coastal Zone Color Scanner. Land vegetation patterns derived from the NOAA–7 AVHRR.

SEA SURFACE TEMPERATURES collected by the NOAA–7 AVHRR range from 24°C to 2°C as colors go from red to yellow to green to blue for July 1984 (middle).

ICE AND SNOW COVER (February 1979). Sea ice is indicated by white, ice sheets by purple, and seasonal snow by various shades of blue representing different snow depths (Nimbus–7 Scanning Multichannel Microwave Radiometer).

TEMPERATURES OF THE GULF STREAM (right) range from 24°C to 2°C as colors go from red to yellow to blue to purple.



release into the atmosphere, thereby amplifying the greenhouse effect?

From space, MODIS will observe the global distribution of phytoplankton over time to help determine how it affects and is affected by fluctuations in the ocean environment. Yet, there are other dynamics equally important in oceanic carbon cycling, such as solar radiation, temperature, and current patterns which dramatically influence phytoplankton productivity and heat transport. Scientists have observed that sea surface temperature (SST) directly influences and is influenced by atmospheric processes. There is a dynamic interrelationship between the ocean and the atmosphere, which in turn impacts the ocean's carbon and heat reservoirs. Storms or upwelling currents may bring up deeper, nutrient-rich waters which serve as "fertilizer" to enhance biological productivity.

CIRRUS CLOUDS over the Western United States.

However, sometimes the ocean's productivity drops dramatically. For instance, Pacific coast fishermen noticed that every three to five years, around December and January, their catch is significantly smaller than average. They named this phenomenon El Niño. Scientists have observed that winds typically push the warmer waters near the surface of the Pacific toward the west, allowing the colder, nutrient-rich water from deeper layers to upwell to the surface where they support a lush phytoplankton population. Oceanic plants and animals depend upon these nutrients. Yet, when the easterly winds die during an El Niño, the upwelling ceases, nutrients are much less abundant, and productivity drops. MODIS will help scientists predict the effects of El Niño on the food chain. Models of El Niño will help Pacific commercial and sport fisheries to better adapt their trade.

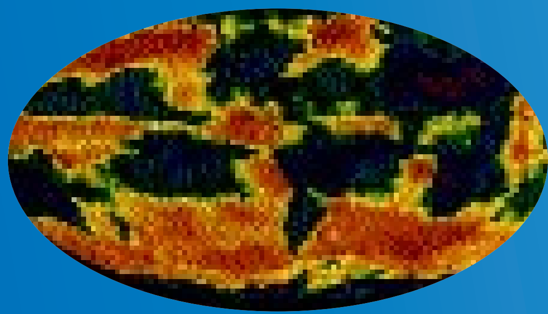
Our Changing Atmosphere

Two important Atmospheric phenomena that MODIS will monitor are clouds and aerosols (liquid or solid particles suspended in the air). Both play a major role in climate; both affect and are affected by the previously discussed land and ocean dynamics. For instance, heavy cloud cover during the day has a cooling effect on the Earth's surface in that clouds reflect and absorb incoming sunlight. Conversely, at night clouds reduce the amount of outgoing radiation, thereby having a warming effect on climate.

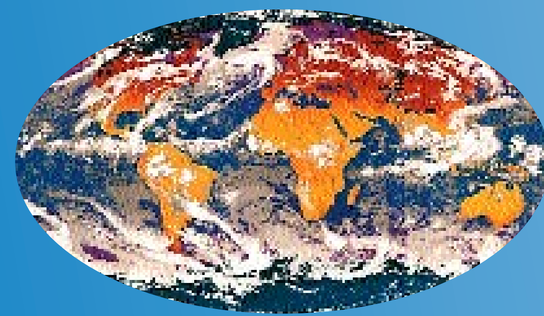
(Philippine Institute of Volcanology & Seismology)

ERUPTION OF MT. PINATUBO (June 15, 1991).

Most clouds do not precipitate; they simply evaporate, leaving any solid or liquid particles they contained suspended in the atmosphere as aerosols. Aerosols affect climate in two ways. First, the particles alter the radiative properties of the atmosphere by absorbing or scattering radiation. Second, aerosols play a critical role in the cloud formation process, serving as a sort of "seed" for attracting condensation. Before evaporating, clouds serve as reaction vessels that convert pollution gases such as SO_2 into aerosol particles. Currently, we have, at best, a poor understanding of the impact of



MEAN CLOUD AMOUNT FOR JULY 1983. Purple and blue are low, and yellow and red are high.



CLOUD COVER FOR OCTOBER 1, 1983

(International Satellite Cloud Climatology Project)

aerosols on climate. Scientists have inadequate data on the global composition and distribution of aerosols. MODIS will monitor the types, areal extent, and loading of aerosols over the Earth. It will also measure their effects on cloud properties and solar radiation. This information will help scientists calculate the effect of aerosols on climate.

Climate models cannot yet accurately quantify the effect of aerosols and clouds on climate. However, their prediction of the impact of certain human activities on climate are very sensitive to the cloud properties used in the models. For example, a global 20 percent increase in the amount of low cloud cover can counteract the expected warming due to the resulting doubling of CO_2 concentration. Alternatively, if aerosol pollution can cause a 20 percent decrease in cloud drop size, this also can counteract this global warming. Improvements in climate models require detailed information on cloud properties, such as area of coverage, cloud-droplet size, cloud-top altitude, cloud-top temperature, and liquid water content. Using MODIS data, scientists will measure these properties and more. Together with data from other sensors on the PM spacecraft, scientists will monitor rainfall over land and oceans to gain a better understanding of the interrelationships among sea surface temperature, soil moisture, and vegetation growth with cloudiness and rainfall.

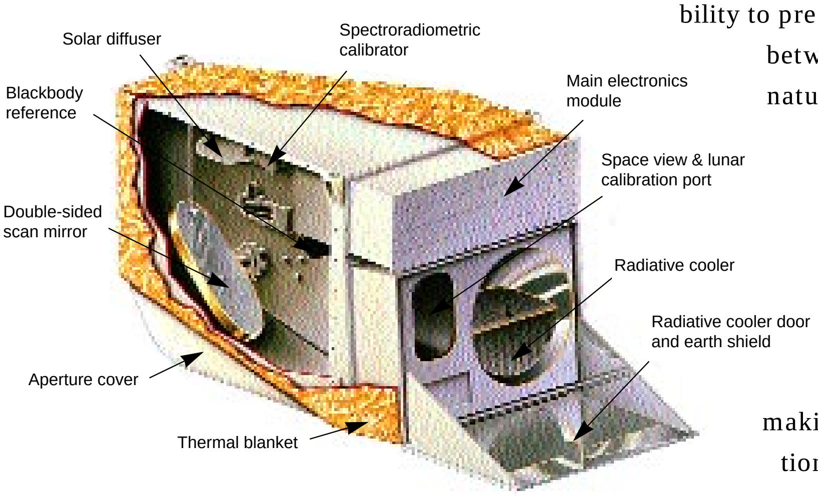
Scientists have shown that clouds play an important role in the transport, transformation, and removal of chemicals in the atmosphere. They estimate that cloud precipitation removes 80 to 90 percent of the particles from the lower atmosphere—such as sulfates and nitrates from anthropogenic emissions, which contribute to acid rain; radioactive particles; and soot particles produced by biomass and fossil fuel burning.

Violent volcanic eruptions can spew aerosols high into the atmosphere where they can remain for months or years above the cloud precipitation processes occurring in the lower atmosphere. Periodically slowing or offsetting the current warming trend, volcanic eruptions may contribute to global cooling. When a volcano erupts with enough force, it sends dust, ash, and sulfur dioxide into the upper atmosphere. The sulfuric acid particles that subsequently form in the stratosphere absorb and scatter incoming solar radiation so that less sunlight reaches the Earth's surface, causing it to cool down. Volcanic particles may also contribute to destruction of ozone—a process that should be closely monitored. MODIS will contain an alarm that will alert scientists where and when a volcano has erupted, enabling them to observe and measure volcanic activity as it is ongoing. The same spectral information will also provide information on the distribution and characteristics of forest fires, which can help scientists estimate the associated emissions of gases and particulates from burning biomass. There is, for example, widespread biomass burning at the southern edge of the Amazon rain forest of South America, as well as in Africa and tropical Asia.

MODIS Science Team

To derive the processes, or algorithms, by which MODIS data will be used to conduct the science discussed throughout this brochure, MODIS employs an international team of scientists consisting of 24 members from the United States, the United Kingdom, Australia, and France. The MODIS Science Team is divided into four discipline groups: Atmosphere, Land, Oceans, and Calibration. The Calibration Group will characterize and monitor the performance of the MODIS instrument to determine the accuracy and validity of its measurements.

MODIS Instrument



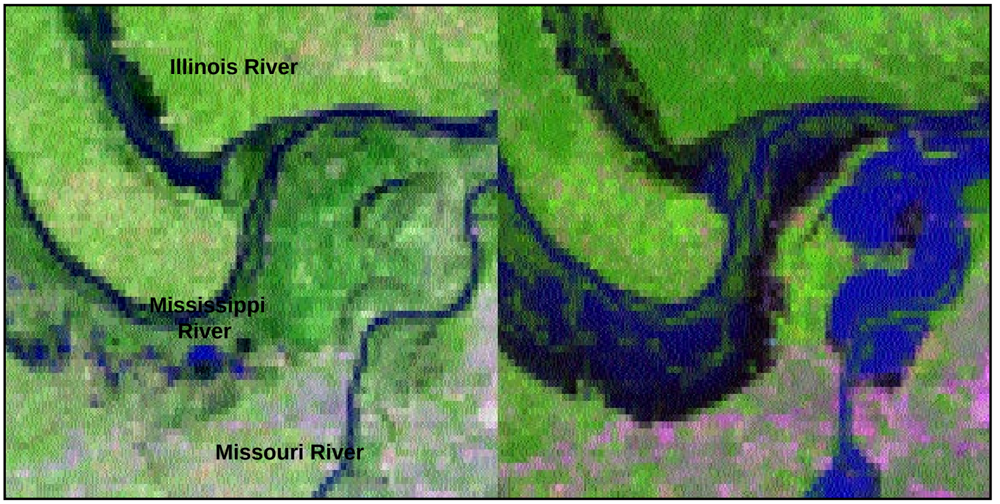
MODIS will have a viewing swath width of 2,330 km and will view the entire surface of the Earth in 36 spectral bands sampling the electromagnetic spectrum from 0.4 to 14 µm with a spatial resolution ranging from 250 to 1,000 meters. It will acquire data at an average rate of 6.1 megabits per second. MODIS data will be processed in high-speed computers, using theoretically and empirically derived algorithms, to yield approximately 40 global data products needed to analyze global change. Each MODIS instrument will have a design life of five years (although they are expected to last longer), and four are expected to be launched between 1998 and 2006 to help develop a 15-year data set for comprehensive global change research. MODIS data will also play a significant role in the interpretation of measurements made by other EOS instruments.

MODIS data, along with data from the other EOS instruments, will be available to the scientific community worldwide. EOS will encourage and facilitate wide use of the data to promote Earth science and interdisciplinary interaction.

Summary of MODIS Objectives

MODIS will help scientists to understand the Earth as a system, from which they can develop the capability to predict future change and to differentiate between the impact of human activities and natural activities on the environment. As stated previously in this brochure, the goal is to construct models of Earth's global dynamics—atmospheric, oceanic, and terrestrial—and predict changes before they occur. Consequently, MODIS data will assist policymakers worldwide in making sound decisions concerning protection and management of our environment and resources.

FLOODING OF THE MISSISSIPPI, ILLINOIS, AND MISSOURI RIVERS NEAR ST. LOUIS, MO. The scene on the left was acquired by the Landsat-5 Thematic Mapper on April 14, 1984. The scene on the right was acquired by the MODIS Airborne Simulator aboard a NASA ER-2 aircraft on July 29, 1993. Both scenes are approximately 34 kilometers by 34 kilometers in size. These scenes, originally acquired at a spatial resolution of 30-50 m, have been degraded to 250 m, corresponding to the resolution that will be achieved by MODIS.

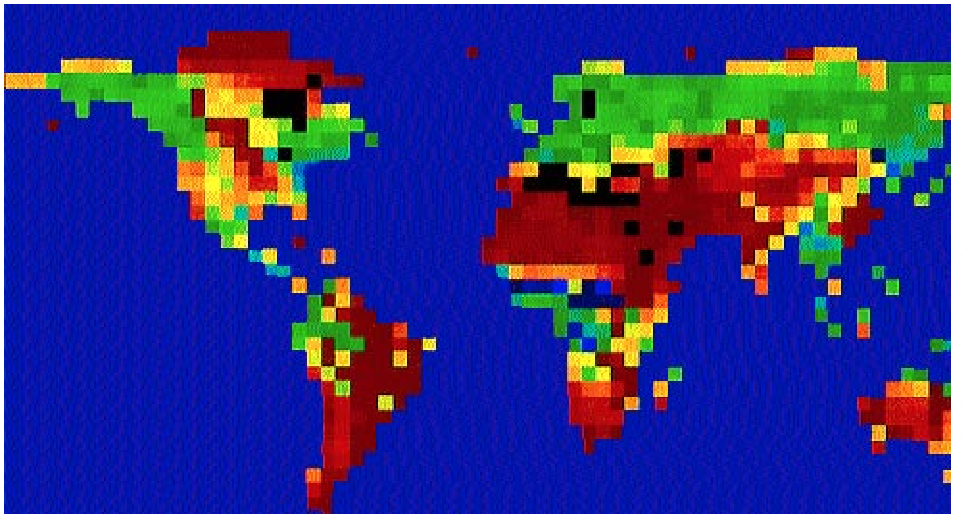


(Goddard Space Flight Center)

(EROS Data Center)

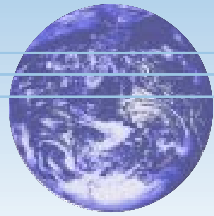
VEGETATION INDEX VALUES. The first prototype global land 1-km AVHRR 10-day composite produced for global change research and as a MODIS precursor data set. Shades of green with a transition to brown represent low index values. Blue represents water and white represents clouds, snow, and other bright features. Black represents missing data.

GLOBAL FIELDS OF PHOTOSYNTHESIS. The leaf area index fields are used within a global biosphere-atmosphere model to calculate global fields of photosynthesis. Satellite data indicate the location of green vegetation, and the model estimates the corresponding level of photosynthetic activity. Dark blue and green areas indicate vigorous vegetation, pink and dark red indicate sparse vegetation.



(EOS Interdisciplinary Science Team: Biosphere—Atmosphere Interactions)

EARTH OBSERVING SYSTEM



MODIS STANDARD DATA PRODUCTS

These are the *principal* MODIS data products that will be available after launch of the EOS spacecraft. Other products will also be developed and made available.

- ◊ **Cloud mask** at 250 m and 1000 m resolution during the day and 1000 m resolution at night.
- ◊ **Aerosol concentration and optical properties** at 5 km resolution over oceans and 10 km over land during the day.
- ◊ **Cloud Properties** (optical thickness, effective particle radius, thermodynamic phase, cloud top altitude, cloud top temperature) at 1-5 km resolution during the day and 5 km resolution at night.
- ◊ **Vegetation and land-surface cover**, conditions, and productivity, defined as:
  - — Vegetation indices corrected for atmospheric effects, soil, polarization, and directional effects.
  - — Surface reflectance.
  - — Land cover type.
  - — Net primary productivity, leaf area index, and intercepted photosynthetically active radiation.
- ◊ **Snow and sea-ice cover and reflectance.**
- ◊ **Surface temperature** with 1 km resolution, day and night, with absolute accuracy goals of 0.3°C – 0.5°C over oceans and 1°C over land.
- ◊ **Ocean color** (ocean-leaving spectral radiance measured to 5 percent), based on data acquired from the MODIS visible and near-infrared channels.
- ◊ **Concentration of chlorophyll-*a*** (within 35 percent) from 0.05 to 50 mg/m^3 for case 1 waters.
- ◊ **Chlorophyll fluorescence** (within 50 percent) at surface water concentrations of 0.5 mg/m^3 of chlorophyll-*a.*

MODIS will fly on both the EOS AM and PM satellites to maximize cloud-free remote sensing of Earth's surface and to exploit synergism with other EOS sensors.

The MODIS instrument is managed by NASA/Goddard Space Flight Center, Greenbelt, Maryland and built by the Hughes Santa Barbara Research Center, Goleta, California. For further information contact: David Herring at (301) 286-9515; herring@ltpsun.gsfc.nasa.gov or acccess the MODIS Homepage via Mosaic at WWW, URL: http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html

MODIS Technical Specifications

Orbit:	705 km, 10:30 a.m. descending node or 1:30 p.m. ascending node, sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (across track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	250 kg
Power:	225 W (orbital average)
Data Rate:	11 Mbps (peak daytime)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2)
(at nadir):	500 m (bands 3-7)
	1000 m (bands 8-36)
Design Life:	5 years

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud Boundaries	1	620- 670	21.8	128
	2	841- 876	24.7	201
Land/Cloud Properties	3	459- 479	35.3	243
	4	545- 565	29.0	228
	5	1230- 1250	5.4	74
	6	1628- 1652	7.3	275
	7	2105- 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405- 420	44.9	880
	9	438- 448	41.9	838
	10	483- 493	32.1	802
	11	526- 536	27.9	754
	12	546- 556	21.0	750
	13	662- 672	9.5	910
	14	673- 683	8.7	1087
	15	743- 753	10.2	586
	16	862- 877	6.2	516
Atmospheric Water Vapor	17	890- 920	10.0	167
	18	931- 941	3.6	57
	19	915- 965	15.0	250

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE∆T(K)[3]
Surface/Cloud Temperature	20	3.660- 3.840	0.45	0.05
	21	3.929- 3.989	2.38	2.00
	22	3.929- 3.989	0.67	0.07
	23	4.020- 4.080	0.79	0.07
Atmospheric Temperature	24	4.433- 4.498	0.17	0.25
	25	4.482- 4.549	0.59	0.25
Cirrus Clouds	26	1.360- 1.390	6.00	150[4]
Water Vapor	27	6.535- 6.895	1.16	0.25
	28	7.175- 7.475	2.18	0.25
	29	8.400- 8.700	9.58	0.05
Ozone	30	9.580- 9.880	3.69	0.25
Surface/Cloud Temperature	31	10.780- 11.280	9.55	0.05
	32	11.770- 12.270	8.94	0.05
Cloud Top Altitude	33	13.185- 13.485	4.52	0.25
	34	13.485- 13.785	3.76	0.25
	35	13.785- 14.085	3.11	0.25
	36	14.085- 14.385	2.08	0.35

[1] Bands 1 to 19, nm; Bands 20-36, µm

[2] (W/m^2-µm-sr)

[3] SNR=Signal-to-noise ratio
NE∆T=Noise-equivalent temperature difference } Performance goal is 30%-40% better than required

[4] SNR

MODIS

"The highest wisdom has but one science—the science of the whole —the science explaining the whole creation and man's place in it."

—Leo Tolstoy